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# Role of Poultry Research in Increasing Consumption of PUFA in Humans

*Hanan Al-Khalafah and Afaf Al-Nasser*

## Abstract

In recent years, polyunsaturated fatty acids (PUFA) have received considerable attention in both human and animal nutrition. As a mean of increasing the low consumption of long chain n-3 PUFA by humans consuming diets, there has been some interest in the enrichment of poultry meat with these fatty acids for people seeking healthy lifestyles. Dietary supplementation with n-3 PUFA, such as these found in fish oil and linseed oil, were found to have nutritional benefits in humans. Modulation of fatty acid profiles as a result of n-3 PUFA incorporation is well documented in humans, rodents, and poultry. The current chapter focuses on enriching poultry meat with these beneficial fatty acids to increase its consumption by human beings.

**Keywords:** health, n-3 fatty acids, polyunsaturated fatty acids, poultry

## 1. Introduction

Recently, PUFA have received considerable attention in both human and animal nutrition, particularly those of the n-3 family; which are distinct due to the placement of the first double bond onto the third carbon atom from the methyl end of the fatty acid molecule. Long-chain fatty acids primarily those with more than 18 carbon atoms, derived mainly from fish oils are consumed quite less along with the other PUFAs. In order to increase their consumption through human diets, has led to studies for enriching the poultry meat infused with these fatty acids and thus enabling people to live healthier lifestyles. Dietary supplementation with n-3 PUFA, such as these found in fish oil and linseed oil, were found to have nutritional benefits in humans [1–5].

This chapter will shed light on the overview, sources, and metabolism of PUFA, their incorporation into cell membrane structure, their involvement in health and clinical problems, enrichment of poultry products with PUFA, and their involvement in immune system.

## 2. Overview of fatty acids

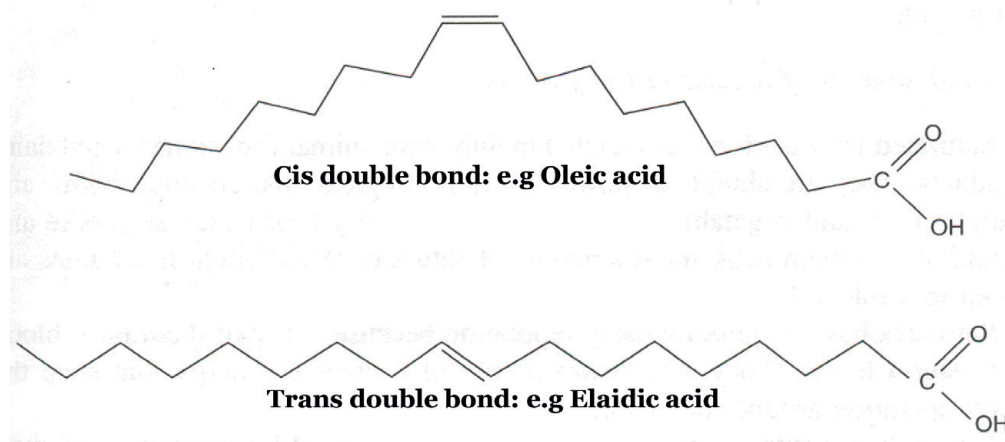
All fatty acids are carboxylic acids characterized by a chain-like structure with a carboxyl group (COOH) at one end, and a methyl group (CH<sub>3</sub>) at the other end.

The rest of the chain consists of carbon atoms varying in length from 2 to 20 or more with hydrocarbon bonds (CH<sub>2</sub>). Fatty acids (FA) differ in the number of hydrogen atoms and the number and location of the double bonds between adjacent carbon atoms if hydrogen atoms are removed. If a fatty acid chain is fully loaded with hydrogen atoms, the FA is termed saturated. Consequently, saturated fatty acids form straight chains as there are no double bonds between carbon atoms. These usually contain between 12 and 24 carbon atoms. This kind of FA is abundantly present in adipose tissues of animals, including poultry and used as a source of energy if needed. An example of a saturated FA is stearic acid (C<sub>18</sub>:0). This is one way to name a fatty acid (C:D) where C is the number of carbon atoms in the fatty acid and D is the number of double bonds in the fatty acid. Sources of saturated FA include meat, dairy products, palm oil, coconut oil and vegetable shortening [6].

If a pair of hydrogen atoms is removed under the influence of specific enzymes, a double bond is formed between adjacent carbon atoms and the saturated FA becomes monounsaturated. An example of a monounsaturated FA is oleic acid (18:1), an n-9 FA that constitutes 74% of total FA in olives. n-x is a nomenclature of fatty acids where a double bond is located on the xth carbon-carbon bond, counting from the terminal methyl carbon (designated as n). Other sources of monosaturated FA are avocados, rapeseed, peanuts and soybeans [7]. If two or more double bonds are formed due to removal of more than a pair of hydrogen atoms, the FA is termed polyunsaturated. The more double bonds a fatty acid has, the more unsaturated it is [8–10]. The main sources of PUFA are seeds and seed oils, oily fish and fish oils [10].

Moreover, the orientation of the fatty acid chain at the site of a double bond determines and characterizes a fatty acid. For example, a FA called cis-configured when both segments of the molecule lie at the same side. On the other hand, in the trans configuration, the two parts of the molecule face opposite with respect to the bond directions (see **Figure 1**). Most PUFA in plants and sea foods are of cis configuration [11].

The two major types of PUFA which play a crucial role in the biological functioning of both, humans and animals are the n-3 and n-6 PUFA. The n-3 PUFA consists of linolenic acid (LNA, C<sub>18</sub>:3), eicosapentaenoic acid (EPA, C<sub>20</sub>:5) and docosahexaenoic acid (DHA, C<sub>22</sub>:6) whereas the n-6 PUFAs comprise mainly linoleic acid (LA, C<sub>18</sub>:2) and arachidonic acid (AA, C<sub>20</sub>:4). LA and  $\alpha$ -LNA are classified as essential fatty acids (EFA) due to their inability to be synthesized by the body. However, these EFAs should be consumed through the diet because of shortage of specific desaturation enzymes. AA can be synthesized in from LA when



**Figure 1.**  
*cis and trans configuration of FA molecules.*

the diet is consumed. In a similar manner, EPA along with DHA can be synthesized from  $\alpha$ -LNA although synthesis between them is inadequate in most conditions. Due to the absence of specific desaturase enzymes, the n-3 and n-6 fatty acids are not inter-convertible. On the other hand, saturated FA such as palmitic acid (C16:0) and stearic acid (C18:0) and most monounsaturated FA such as oleic acid (C18:1 n-9) can be synthesized in the human body from precursors such as glucose or amino acids [12, 13]. **Table 1** shows a list of the common saturated and unsaturated fatty acids.

Common name	FA name
Butyric	C4:0
Caproic	C6:0
Caprylic	C8:0
Capric	C10:0
Undecanoic	C11:0
Lauric	C12:0
Tridecanoic	C13:0
Myristic	C14:0
Myristoleic	C14:1
Pentadecanoic acid	C15:0
c10 Pentadecanoic acid	C15:1
Palmitic	C16:0
Palmitoleic	C16:1
cis-10-heptadecanoic	C17:1
Stearic	C18:0
Elaidic	C18:1n9t
Oleic	C18:1n9c
Linolelaidic	C18:2n6t
Linoleic	C18:2n6c
Arachidic	C20:0
$\gamma$ -Linolenic	C18:3n6
$\alpha$ -Linolenic	C18:3n3
Heneicosanoic	C21:0
c11, 14 Eicosadienoic	C20:2
Behenic	C22:0
c8,11,14 Eicosatrienoic	C20:3n6
Erucic acid	C22:1 n9
c11,14,17 Eicosatrienoic	C20:3n3
Arachidonic	C20:4n6
Tricosanoic	C23:0
c13,16 Docosadienoic	C22:2
Eicosapentaenoic acid (EPA)	C20:5n3
Lignoceric	C24:0
Nervonic	C24:1
Docosapentaenoic acid (DPA)	C22:5n3
Docosahexaenoic acid (DHA)	C22:6n3

**Table 1.**  
*List of common saturated and unsaturated fatty acids.*

### 3. Sources and metabolism of fatty acids

General speaking, there are small amounts of AA in fish. However Brown et al. [14] have reported that there is 4.8–14.3% AA in some Australian fish species. However, fish oil contains high amounts of EPA and DHA. These fatty acids are synthesized by phytoplankton that are consumed by fish. Some fish species may contain more than 30% n-3 PUFA about 50% of the FA in fish is PUFA, of which about 30% are n-3 FA [15, 16].

Conversely, the presence of  $\alpha$ -LNA in seafood is almost nil; although plant sources like chia, linseed, rapeseed, perilla and blackcurrant possess high amounts of this FA, this is because these plant sources have  $\Delta 12$ -desaturase that converts oleic acid into LA, this is further converted into  $\alpha$ -LNA under the influence of  $\Delta 15$ -desaturase [10]. Linseed is one of the richest know sources of  $\alpha$ -LNA, as it contains almost 60% of this fatty acid in its oil [17].

Some algal oil and algal biomass obtained from marine regions are known to be good sources of DHA and EPA and thus can be used as a means to enrich meats and eggs using these long chain fatty acids. This has proved to be successful and is well documented in literature, even though DHA is mostly obtained from these algal biomasses [18–26].

In addition, echium oil from the plant *Echium plantagineum* has been recognized as an ideal source of stearidonic acid (C18:4n-3) that is naturally converted to the important long-chain n-3 fatty acid, EPA, when metabolized in the body [27, 28]. In

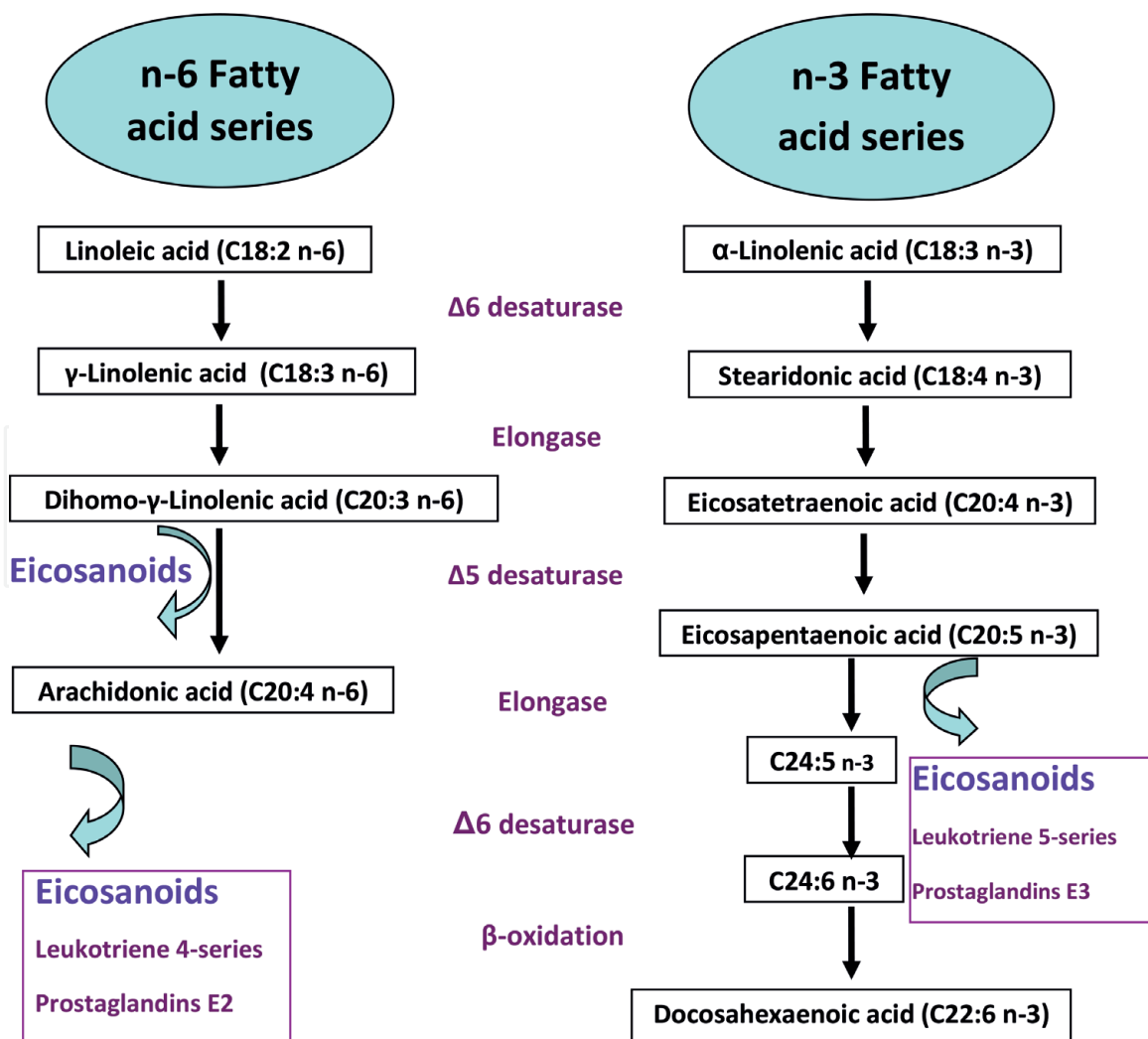


Figure 2. Metabolic pathways of the long chain n-3 and n-6 PUFA.



addition, there are considerable amounts of  $\alpha$ -linolenic acid and  $\gamma$ -linolenic acid in the echium oil as well. Rymer et al. [29] showed that  $\gamma$ -linolenic acid is accumulated as stearidonic acid increases in the chicken's diet.

N-3 PUFA, particularly EPA and DHA, are reported to compete with AA for incorporation in the phospholipid bilayer of cell membranes of all body cells, especially erythrocytes, platelets, neutrophils, monocytes and liver cells [30, 31]. Both AA and EPA are parent precursors of different kinds of eicosanoids that play a crucial role in the inflammatory responses in both humans and animals, including poultry.

Initially, the dietary essential fatty acid  $\alpha$ -LNA is converted to EPA and DHA while LA is converted to AA by elongation and desaturation reactions [32–34]. These conversion reactions are mediated in humans by three desaturases,  $\Delta 9$ ,  $\Delta 6$ , and  $\Delta 5$ . The desaturases work by introducing a double bond at a specific position of the carbon backbone. Nakamura and Nara [35] have reported that desaturases in mammals are regulated at the transcriptional level and their transcription is genetically controlled. However, regulation of  $\Delta 9$  desaturase differs from  $\Delta 6$  and  $\Delta 5$  desaturases because the  $\Delta 9$ -desaturase converts the nonessential stearic acid (18:0) to oleic acid (18:1 n-9). Oleic acid can go through the same steps of desaturation and elongation as LA and  $\alpha$ -LNA, resulting in the synthesis of the fatty acids 20:3 n-9 and 22:4 n-9. Consequently, the  $\Delta 9$ -desaturation provides an alternative to  $\Delta 6$  and  $\Delta 5$  desaturation when the cell is subject to essential fatty acid deficiency. However in the case of availability of sufficient amounts of essential fatty acids, AA and EPA act as precursors for eicosanoid synthesis, although EPA metabolism predominates [32, 33, 36, 37]. When sources rich in stearidonic acid (SDA) such as echium oil are consumed, the body deposits EPA directly in tissues such as plasma, blood leukocytes, liver, breast and legs of human, rodents and chicken because SDA does not require  $\Delta 6$  desaturase activity to form EPA [28, 38–43].

Under the influence of  $\Delta 6$  desaturase, free  $\alpha$ -LNA is converted to SDA (18:4 n-3) then to eicosatetraenoic acid (20:4 n-3) by an elongase. Next,  $\Delta 5$  desaturase acts on eicosatetraenoic acid and converts it into EPA (20:5 n-3). Elongase converts EPA into the FA (24:5 n-3) that is converted into the FA (24:6 n-3) by the action of  $\Delta 6$  desaturase. Then, oxidation of (24:6 n-3) by  $\beta$ -oxidase produces DHA. During this metabolic pathway, eicosanoids such as leukotriene 5-series, prostaglandins E3 and thromboxane A3 are derived from EPA [37, 41, 44–50]. **Figure 2** shows the metabolic pathway of the long chain n-3 and n-6 PUFA [35].

#### **4. Incorporation into cell membrane structure**

Cell membranes consist of a variety of molecules that enable cells to survive via various biological interactions. Proteins and lipids are the main elements of cell membranes. Different cell types have different cell membrane lipids and proteins that reflect different biological functions and specializations of cells.

Lipids in the cell membranes are arranged in a bilayer structure with the hydrophobic moieties in the center of the membrane and the hydrophilic heads at the two surfaces, facing the inner cytoplasm and the outside surrounding. There are three main types of lipids in the cell membranes, namely: phospholipids, glycolipids, and steroids. Both saturated and unsaturated FA are attached to the glycerol moiety in the cell membrane, with the saturated FA attached to the first carbon atom in the glycerol backbone (sn-1), while PUFA occupy the sn-2 position [17]. Membrane fluidity is highly affected by the length and the degree of unsaturation of FA chains. Lipid moieties within the cell membrane determine different biological cellular functions such as intracellular pathways and receptors formation. In humans, EPA,

DHA, AA and oleic acid are the main PUFA incorporated into the cell membranes. Interestingly, changes in these lipid moieties leads to changes in biological functions of different cell types due to the production of different cellular intermediates such as leukotrienes, prostacyclins and prostaglandins. These intermediates are involved in the immunomodulatory effect of PUFA [42, 49, 51–60].

## **5. Involvement in health and clinical problems**

Vitality of living cells depends profoundly on dietary lipids that are incorporated into phospholipid layers of cellular membranes as a result there is a constant competition between the omega-3 fatty acids; eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), with arachidonic acid (AA) for this incorporation. As AA controls the upregulation of eicosanoids such as leukotrienes, this competitive inhibition downregulates inflammation responses related to man, which are associated to numerous diseases and disorders such as cardiovascular disease, increased triglycerides, blood pressure, thrombosis, atherosclerosis, stress, mental problems, asthma and rheumatoid arthritis [21, 50, 61–79]. These benefits of an optimal ratio of n-3/n-6 PUFAs on health are just a few examples of a wide range of clinical problems that are improved by consumption of the very long chain n-3 fatty acids.

## **6. n-3 enrichment of poultry diet**

Traditionally, fish and fish oil are the main sources of essential, long chain n-3 PUFA that induce modifications in the lipid composition of poultry products because marine sources in general contain high levels of EPA and DHA PUFA. Of less nutritional importance are plant sources such as linseed that is rich in  $\alpha$ -linolenic acid ( $\alpha$ -LNA).  $\alpha$ -LNA is an 18 carbon n-3 fatty acid that is the precursor to the long chain n-3 PUFA, but because the efficiency of conversion is so low in humans, the accumulation of  $\alpha$ -LNA is of little real nutritional benefit.

In chickens, there are number of studies that investigated effects of PUFA on fatty acid profile of different tissues, if sources rich in these fatty acids are added to the poultry feed. Bou et al. [80] reported that supplementing the diet of broilers with 2.5% fish oil produced double the amount of EPA and DHA in their carcass than diets supplied with 1.25% fish oil. In another study, Ratnayake et al. [81] fed broiler chickens increasing levels of redfish meal (40–120 g/kg) for a period of 42 days. The effect of this dietary manipulation on fatty acid composition of breast and thigh muscles was investigated. Authors of this study observed a linear relationship between the level of the dietary fish meal and the proportions of DHA, DPA and EPA in the meat muscles. Givens and Rymer [82] also conducted an experiment to investigate the effect of poultry species and genotype on the efficiency of incorporation of n-3 PUFA in poultry meat. The two genotypes of turkeys (Wrolstad and BUT T8) and broilers (Ross 308 and Cobb 500) were fed one or four diets that contained 50 g/kg added oil; either vegetable oil (control), partially replaced with linseed (20 or 40 g/kg), FO (20 or 40 g/kg), or mixture of linseed and FO (20 g linseed and 20 g FO/kg diet). It was observed that on replacement of the control diet with either low or high levels of FO caused a significant increase in the concentration of EPA and DHA in all the meats whereas feeding linseed-enriched diet significantly increased the concentration of  $\alpha$ -linolenic acid. No significant difference was noted with the incorporation of n-3 PUFA between the two broiler genotypes. Turkey genotypes were only different in the case of  $\alpha$ -linolenic acid incorporation. It was also seen that there was a greater incorporation of DHA in

white than in dark meat. In order to confirm the effect of dietary fatty acid modulation in broiler chickens, another study was conducted by Lopez-Ferrer et al. [83]. Here, a diet enriched with 8.2% FO was fed to broilers for duration of 5 weeks, after this it was replaced by diets containing 8.2% linseed or rapeseed in three different periods: the last week before slaughtering, the last 2 weeks and throughout the experiment. The end results for the fatty acid analysis of thigh and breast showed that the total amounts of n-3 PUFA were significantly decreased after removal of FO diet. Upon replacement of FO with the linseed diet caused a substantial increase in  $\alpha$ -linolenic acid, furthermore there was an increase in the total amounts of n-6 PUFA and a decrease in the DHA proportions due to its limited conversion to longer n-3 PUFA. When FO was replaced by rapeseed there was an increase in the total amounts of monounsaturated fatty acids, especially oleic acid.

Recently, Zelenka et al. [84] studied the effect of increasing levels of linseed oil in the diets of chickens and its influence on the fatty acid content in breast and thigh meat of chickens. Linseed oil at levels of 1, 3, 5 or 7% were fed to broiler chickens from 25 to 40 days of age. Oils were derived from the linseed cultivar *Atalante* with a high content of  $\alpha$ -linolenic acid or the cultivar *Lola* with a high content of linoleic acid. Results showed that feeding a diet with a high content of  $\alpha$ -linolenic acid significantly increased all n-3 PUFA, decreased n-6 PUFA and decreased the ratio of n-6/n-3 PUFA. On the contrary, when the birds were fed a diet with a high content of linoleic acid, this caused a significant increase in the levels of all n-6 PUFA in thigh and breast of chickens. Similarly, a study by Kartikasari et al. [85] showed that feeding broilers on diets with a high content of  $\alpha$ -linolenic acid, while keeping a constant linoleic acid level, significantly increased the incorporation of all n-3 PUFA into breast and thigh meat by 5 and 4-fold compared to chickens fed low  $\alpha$ -linolenic acid content. In another experiment [86], the authors fed broiler chickens on diets with constant level of  $\alpha$ -linolenic acid (2.1%) and different levels of linoleic acid, which included 2.9–4.4%, and consisted of pure or blended vegetable oils such as macadamia, flaxseed and sunflower oils. The overall lipid content was kept at a constant of 5%. Post analysis it was observed that chickens when fed diets the lowest linoleic acid content (2.9%) contributed towards higher incorporation of total n-3 PUFA in the breast by 16% compared with feeding the highest linoleic acid content (4.4%). When the chickens were fed with a diet with a high content of linoleic acid, this resulted in a significant reduction in EPA levels in both thigh and breast tissues. The levels for DPA and DHA were not affected by dietary linoleic acid. Authors suggested that this could be due to fact that linoleic acid competes with  $\alpha$ -linolenic acid for  $\Delta^6$  desaturase. In other words, high dietary level of linoleic acid might reduce the conversion of  $\alpha$ -linolenic to n-3 PUFAs. In a further study [87], the authors fed broiler chickens on diets containing 0, 2, or 4% linseed oil plus tallow to make 8% added fat throughout 38 growth period. The total amounts of saturated and monounsaturated fatty acids were significantly decreased after feeding increased levels of linseed. Conversely, the total amounts of PUFA were significantly increased. A recent study [88] showed that upon supplementing n-3 PUFA, in the form of linseed oil (3/100 g mixed feed), in the diet of laying hens resulted in a significant increase in  $\alpha$ -linolenic of the plasma. The same study also revealed that, FO administration (same dose as linseed) caused a significant increase in the proportion of plasma EPA and DHA.

## **7. Involvement in avian immune function**

The immunomodulatory effect of PUFA in broiler chickens occurs by affecting intercellular communications and signals that change the reactivity of leukocytes upon antigenic stimulation. This effect is highly associated with down-regulation or



up-regulation of different cytokines that are believed to affect the avian immune function such as IL-1 $\beta$ , IFN $\gamma$ , MGF, IL-1, IL-4, IL-2 [89–92].

There is some concern that diets enriched with n-3 PUFA have detrimental effects on chicken immunity and impair resistance to infection. However, it is not clear whether this concern is justified, since some studies show no effect [93], some show a detrimental effect [94] while some show an improvement [89, 90, 93, 95–97] in chicken immune response following feeding of n-3 PUFA.

## **8. Conclusion**

Consumption of omega-3 fatty acids should be increased in human diets to get the beneficial effects of these fatty acids. One way to achieve this goal is by enriching poultry meat and eggs with omega-3 fatty acids, which is proved to be very successful. This role of poultry production in enhancing health aspects of human needs more research and interest from nutritionists and poultry producers.

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## **Conflict of interest**


There is no conflict of interest related to the current work.

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## References

- [1] Al-Khalifa H. Production of added-value poultry meat: Enrichment with n-3 polyunsaturated fatty acids. *World's Poultry Science Journal*. 2015;**71**(2): 319-326
- [2] Al-Khalifa H, Al-Nasser A, Al-Bahouh M, Ragheb G, Al-Qalaf S, Al-Omani N, et al. The effect of polyunsaturated fatty acids on avian immune cell subpopulations in peripheral blood, spleen, and thymus. *World's Poultry Science Journal*. 2016;**1**: 1-4
- [3] Abbaci K, Joachirn S, Garric J, Boisseaux P, Exbrayat JM, Porcher JM, et al. Anatomical and histological characterization of the gametogenesis of *Radix balthica* (linnaeus, 1758) in comparison with *Lymnaea stagnalis* (linnaeus, 1758). *Journal of Histology & Histopathology*. 2017;**4**:5
- [4] Apperson KD, Cherian G. Effect of whole flax seed and carbohydrase enzymes on gastrointestinal morphology, muscle fatty acids, and production performance in broiler chickens. *Poultry Science*. 2017;**96**(5): 1228-1234
- [5] Colussi G, Catena C, Novello M, Bertin N, Sechi LA. Impact of omega-3 polyunsaturated fatty acids on vascular function and blood pressure: Relevance for cardiovascular outcomes. *Nutrition, Metabolism, and Cardiovascular Diseases*. 2017;**27**(3):191-200
- [6] Rees AM, Austin MP, Parker G. Role of omega-3 fatty acids as a treatment for depression in the perinatal period. *Australian and New Zealand Journal of Psychiatry*. 2005;**39**(4):274-280
- [7] Reeves JB, Weihrauch JL. Composition of Foods. Fats and Oils. Agriculture Handbook. Washington, DC: USDA; 1979
- [8] Castro-Gonzalez MI. Omega 3 fatty acids: Benefits and sources. *Interciencia*. 2002;**27**(3):128-136
- [9] Budowski P. Oils rich in omega-3 fatty acids—health implications. *Harefuah*. 1995;**128**(2):121-125
- [10] Nettleton JA. omega -3 fatty acids: Comparison of plant and seafood sources in human nutrition. *Journal of the American Dietetic Association*. 1991;**91**(3):331-337
- [11] Ackman RG, Marine lipids and omega-3 fatty acids. In: Akoh CC, editor. (Functional Foods and Nutraceuticals Series), in *Handbook of functional lipids*. Boca Raton: Taylor & Francis; p. 311-324
- [12] Landmark K. Alpha-linolenic acid, cardiovascular disease and sudden death. *Tidsskrift for den Norske Lægeforening*. 2006;**126**(21):2792-2794
- [13] Herbaut C. Omega-3 and health. *Revue Médicale de Bruxelles*. 2006;**27**(4):355-360
- [14] Brown AJ, Roberts DCK, Truswell AS. Fatty acid composition of Australian marine finfish: A review. *Food Australia*. 1989;**1**:655-666
- [15] Kris-Etherton MKP, Harris WS, Appel LJ. Fish consumption, fish oil, omega-3 fatty acids, and cardiovascular disease. *Journal of the American Heart Association*. 2002;**106**:2747-2773
- [16] Kartal M, Kurucu S, Aslan S, Ozbay O, Ceyhan T, Sayar E, et al. Comparison of n-3 fatty acids by GC-MS in frequently consumed fish and fish oil preparations on the Turkish market. *FABAD Journal of Pharmaceutical Sciences*. 2003;**28**:201-205

- [17] Alexander JW. Immunonutrition: The role of omega –3 fatty acids. *Nutrition*. 1998;**14**(7/8):627-633
- [18] Holub BJ. Clinical nutrition: 4. Omega-3 fatty acids in cardiovascular care. *Canadian Medical Association Journal*. 2002;**166**(5):608-615
- [19] Simopoulos AP. Health effects of [Omega]3 polyunsaturated fatty acids in seafoods. In: *World Review of Nutrition and Dietetics*. Vol. 66. Basel; London: Karger; 1991
- [20] Simopoulos AP. Human requirement for n-3 polyunsaturated fatty acids. *Poultry Science*. 2000;**79**(7): 961-970
- [21] Simopoulos AP. Importance of the ratio of omega-6/omega-3 essential fatty acids: Evolutionary aspects. (*World Review of Nutrition and Dietetics*). In: Simopoulos AP, Cleland LG, editors. *Omega-6/Omega-3 Essential Fatty Acid Ratio: The Scientific Evidence*. Vol. 92. Basel, Switzerland: Karger AG; 2003. pp. 1-22
- [22] Singer P, Wirth M. Omega-3 fatty acids of marine and vegetable origin: State of the art. *Ernahrungs-Umschau*. 2003;**50**(8):296-304
- [23] Rymer C, Givens DI. N-3 fatty acid enrichment of edible tissue of poultry: A review. *Lipids*. 2005;**40**(2):121-129
- [24] Cheng CH, Shen TF, Chen WL, Ding ST. Effects of dietary algal docosahexaenoic acid oil supplementation on fatty acid deposition and gene expression in laying leghorn hens. *The Journal of Agricultural Science*. 2004;**142**:683-690
- [25] Cachaldora P, Grcia-Rebollar P, Alvarez C, Mendez J, de Blas JC, Mendez J. Effect of type and level of basal fat and level of fish oil supplementation on yolk fat composition and n-3 fatty acids deposition efficiency in laying hens. *Animal Feed Science and Technology*. 2008;**141**:104-114
- [26] WooCheol J, Jeong Yeoul L, Sangho K, Sangjin L, ByeongDae C, SeokJoong K. Production of DHA-rich meats and eggs from chickens fed fermented soybean meal by marine microalgae (*Schizochytrium mangrovei* MM103). *Korean Journal of Poultry Science*. 2008; **35**:255-265
- [27] Miller MR, Nichols PD, Carter CG. Replacement of dietary fish oil for atlantic salmon parr (*Salmo salar* L.) with a stearidonic acid containing oil has no effect on omega-3 long-chain polyunsaturated fatty acid concentrations. *Comparative Biochemistry and Physiology. Part B, Biochemistry & Molecular Biology*. 2007;**109**:1226-1236
- [28] Kitessa SM, Young P. Echium oil is better than rapeseed oil in enriching poultry meat with n-3 polyunsaturated fatty acids, including eicosapentaenoic acid and docosapentaenoic acid. *British Journal of Nutrition*. 2009;**101**:709-715
- [29] Rymer C, Gibbs RA, Givens DI. Comparison of algal and fish sources on the oxidative stability of poultry meat and its enrichment with omega-3 polyunsaturated fatty acids. *Poultry Science*. 2010;**89**(1):150-159
- [30] Simonopoulos AP. Is insulin resistance influenced by dietary linoleic acid and trans fatty acids? *Free Radical Biology and Medicine*. 1994;**17**(4): 367-372
- [31] Surai PF, Sparks NHC. Tissue-specific fatty acid and alpha -tocopherol profiles in male chickens depending on dietary tuna oil and vitamin E provision. *Poultry Science*. 2000;**79**(8): 1132-1142
- [32] Voss A, Reinhart M, Sankarappa S, Sprecher H. The metabolism of 7,10,13,16,19-docosapentaenoic acid to 4,7,10,13,16,19-docosahexaenoic acid in

rat liver is independent of a 4-desaturase. *The Journal of Biological Chemistry*. 1991;**266**:19995-20000

[33] Mohammed B, Sankarappa S, Geiger M, Sprecher H. Reevaluation of the pathway for the metabolism of 7,10,13,16-docosatetraenoic acid to 4,7,10,13,16 docosapentaenoic acid in rat liver. *Archives of Biochemistry and Biophysics*. 1995;**317**:179-184

[34] Yaqoob P, Calder PC. N-3 polyunsaturated fatty acids and the immune system. *Recent Research Developments in Lipids - Research*. 1997;**1**:31-61

[35] Nakamura MT, Nara TY. Structure, function, and dietary regulation of Delta 6, Delta 5, and Delta 9 desaturases. *Annual Review of Nutrition*. 2004;**24**: 345-376

[36] Calder PC. N-3 polyunsaturated fatty acids and mononuclear phagocyte function. In: Kremer J, editor. *Medical Fatty Acids in Inflammation*. Switzerland: Birkhauser Verlag Basel; 1998

[37] Calder PC, Bond JA, Harvey DJ, Gordon S, Newsholme EA. Uptake and incorporation of saturated and unsaturated fatty acids into macrophage lipids and their effect upon macrophage adhesion and phagocytosis. *The Biochemical Journal*. 1990;**269**(3): 807-814

[38] Surette ME, Edens M, Chilton FH, Tramposch KM. Dietary echium oil increases plasma and neutrophil long-chain (n-3) fatty acids and lowers serum triacylglycerols in hypertriglyceridemic humans. *The Journal of Nutrition*. 2004; **134**(6):1406-1411

[39] Yang Q, O'Shea TM. Dietary echium oil increases tissue (n-3) long-chain polyunsaturated fatty acids without elevating hepatic lipid concentrations in premature neonatal rats. *The Journal of Nutrition*. 2009;**139**(7):1353-1359

[40] Whelan J. Dietary stearidonic acid is a long chain (n-3) polyunsaturated fatty acid with potential health benefits. *The Journal of Nutrition*. 2009;**139**:5-10

[41] Whelan J, Rust C. Innovative dietary sources of n-3 fatty acids. *Annual Review of Nutrition*. 2006;**26**: 75-103

[42] Miles EA, Banerjee T, Dooper MM, M'Rabet L, Graus YM, Calder PC. The influence of different combinations of gamma-linolenic acid, stearidonic acid and EPA on immune function in healthy young male subjects. *The British Journal of Nutrition*. 2004;**91**:893-903

[43] James MJ, Ursin VM, Cleland LG. Metabolism of stearidonic acid in human subjects: Comparison with the metabolism of other n-3 fatty acids. *The American Journal of Clinical Nutrition*. 2003;**77**:1140-1145

[44] Lopez-Ferrer S, Baucells MD, Barroeta AC, Grashorn MA. Metabolism and nutrition. n-3 Enrichment of chicken meat using fish oil: Alternative substitution with rapeseed and linseed oils. *Poultry Science*. 1999;**78**(3):356-365

[45] Bibus DM, Stitt PA. Metabolism of alpha -linolenic acid from flaxseed in dogs. In: *The Return of Omega 3 Fatty Acids into the Food Supply*. 1. Land-Based Animal Food Products and Their Health Effects. Basel, Switzerland: S Karger AG; 1998. pp. 186-198

[46] Drevon CA, Baksaas I, Krokan H. Omega-3 fatty acids: Metabolism and Biological Effects. Basel, Boston: Birkh auser Verlag; 1993;**1**:389

[47] Fischer S, Von Schacky C, Siess W, Strasser T, Weber PC. Uptake, release and metabolism of docosahexaenoic acid in human platelets and neutrophils. *Biochemical and Biophysical Research Communications*. 1984;**120**:907-918

[48] Calder PC. Polyunsaturated fatty acids and inflammation. *Prostaglandins,*



Leukotrienes and Essential Fatty Acids. 2006;**75**:197-202

[49] Calder PC. The relationship between the fatty acid composition of immune cells and their function. Prostaglandins, Leukotrienes and Essential Fatty Acids. 2008;**79**:101-108

[50] Calder PC, Yaqoob P, Thies F, Wallace FA, Miles EA. Fatty acids and lymphocyte functions. British Journal of Nutrition. 2002;**87**(Supplement 1: S31-S48

[51] Calder PC. n-3 Polyunsaturated fatty acids, inflammation, and inflammatory diseases. The American Journal of Clinical Nutrition. 2006; **83**(1):1505-1519

[52] Kew S, Banerjee T, Minihane AM, Finnegan YE, Williams CM, Calder PC. Relation between the fatty acid composition of peripheral blood mononuclear cells and measures of immune cell function in healthy, free-living subjects aged 25-72 y. The American Journal of Clinical Nutrition. 2003;**77**(5):1278-1286

[53] Yaqoob P, Pala HS, Cortina-Borja M, Newsholme EA, Calder PC. Encapsulated fish oil enriched in alpha-tocopherol alters plasma phospholipid and mononuclear cell fatty acid compositions but not mononuclear cell functions. European Journal of Clinical Investigation. 2000;**30**(3): 260-274

[54] Calder PC. Dietary fish oil appears to prevent the activation of phospholipase c -gamma in lymphocytes. Biochimica et Biophysica Acta. 1998;**1392**:300-308

[55] Calder PC. N-3 polyunsaturated fatty acids, inflammation and immunity: Pouring oil on troubled waters or another fishy tale? (Special issue: Celebrating exciting nutrition research in the next century). Nutrition Research. 2001;**21**(1/2):309-341

[56] Calder PC. Fatty acids and lymphocytes functions. British Journal of Nutrition. 2002;**87**(1):31-48

[57] Calder PC. Long-chain polyunsaturated fatty acids and inflammation. Scandinavian Journal of Food and Nutrition. 2006;**50**(1 sup. 2): 54-61

[58] Yaqoob P, Calder P. Effects of dietary lipid manipulation upon inflammatory mediator production by murine macrophages. Cellular Immunology. 1995;**163**(1):120-128

[59] Yaqoob P, Newsholme EA, Calder PC. The effect of fatty acids on leucocyte subsets and proliferation in rat whole blood. Nutrition Research. 1995;**15**(2):279-287

[60] Yaqoob P, Newsholme EA, Calder PC. The effect of dietary lipid manipulation on rat lymphocyte subsets and proliferation. Immunology. 1994; **82**:603-610

[61] Bavelaar FJ, Hovenier R, Lemmens AG, Beynen AC. High intake of linoleic or alpha -linolenic acid in relation to plasma lipids, atherosclerosis and tissue fatty acid composition in the Japanese quail. International Journal of Poultry Science. 2004;**3**(11):704-714

[62] Cyrus T. Disruption of the 12/15-lipoxygenase gene diminishes atherosclerosis in apo E-deficient mice. The Journal of Clinical Investigation. 1999;**103**:1597-1604

[63] Calder PC. Dietary modification of inflammation with lipids. Proceedings of the Nutrition Society. 2002;**61**(3): 345-358

[64] Volker DH. Fat manipulation in the treatment of rheumatoid arthritis: A review. Journal of Nutraceuticals, Functional & Medical Foods. 2000;**3**(1): 5-31



- [65] Arm P, Horton C, Mencia-Huerta J. Effect of dietary supplementation with fish oil lipids on mild asthma. *Thorax*. 1988;**43**:84-92
- [66] Arm I, Horton C, Spur B, Mencia-Huerta J, Lee T, Am T. The effects of dietary supplementation with fish oil lipids on the airways response to inhaled allergen in bronchial asthma. *American Review of Respiratory Diseases*. 1989;**139**:1395-1400
- [67] Simopoulos AP. Omega-3 fatty acids in inflammation and autoimmune diseases. *Journal of the American College of Nutrition*. 2002;**21**(6): 495-505
- [68] Sellmayer A, Schrepf R, Theisen K, Weber PC. Role of omega-3 fatty acids in cardiovascular disease prevention. *Deutsche Medizinische Wochenschrift*. 2004;**129**(38):1993-1996
- [69] Schwalfenberg G. Omega-3 fatty acids: Their beneficial role in cardiovascular health. *Canadian Family Physician*. 2006;**52**(JUN):734-740
- [70] Nettleton JA. *Omega-3 Fatty Acids and Health*. New York; London: Chapman & Hall; 1995. p. 359
- [71] Leaf A, Kang JX. Omega-3 fatty acids and cardiovascular disease (World Review of Nutrition and Dietetics, Vol. 89). In: Simopoulos AP, Pavlou KN, editors. *Nutrition and Fitness 1: Diet, Genes, Physical Activity and Health*. Basel Switzerland: S Karger AG; 2001. pp. 161-172
- [72] Connor WE. Omega –3 Fatty acids and heart disease. In: Kritchevsky D, Carroll KK, editors. *Nutrition and Disease Update: Heart Disease*. Champaign: American Oil Chemists' Society (AOCS); 1994. pp. 1-137
- [73] Budowski P. Omega 3-Fatty acids in health and disease. *World Review of Nutrition and Dietetics*. 1988;**57**:214-274
- [74] Woods A, Brull D, Humphries S, Montgomery H. Genetics of inflammation and risk of coronary artery disease: The central role of interleukin-6. *European Heart Journal*. 2000;**21**:1574-1583
- [75] Connor WE, Neuringer M, Lin DS. Dietary effects on brain fatty acid composition: The reversibility of n-3 fatty acid deficiency and turnover of docosahexaenoic acid in the brain, erythrocytes and plasma of rhesus monkeys. *Journal of Lipid Research*. 1990;**31**:237-247
- [76] Nkondjock A, Shatenstein B, Maisonneuve P, Ghadirian P. Specific fatty acids and human colorectal cancer: An overview. *Cancer Detection and Prevention*. 2003;**27**(1):55-66
- [77] Prasad KN, Kumar B, Yan XD, Hanson AJ, Cole WC. Alpha - Tocopheryl succinate, the most effective form of vitamin E for adjuvant cancer treatment: A review. *Journal of the American College of Nutrition*. 2003; **22**(2):108-117
- [78] Cotter PF, Sefton AE, Lilburn MS. Manipulating the immune system of layers and breeders: Novel applications of mannan oligosaccharides. In: Lyons TP, Jacques KA editors. *Nutritional Biotechnology in the Feed and Food Industries*. UK, Stamford: Alltech; 2002. p. 21-27
- [79] Koller M, Senkal M, Kemen M, Konig W, Zumtobel V, Muhr G. Impact of omega-3 fatty acid enriched TPN on leukotriene synthesis by leukocytes after major surgery. *Clinical Nutrition*. 2003;**22**(1):59-64
- [80] Bou R, Guardiola F, Tres A, Barroeta AC, Codony R. Effect of dietary fish oil, alpha-tocopherol acetate, and zinc supplementation on the composition and consumer acceptability of chicken meat. *Poultry Science*. 2004; **83**:282-292

- [81] Ratnayake WMN, Ackman RG, Hulan HW. Effect of redfish meal enriched diets on the taste and n-3 pufa of 42-day-old broiler chickens. *Journal of the Science of Food and Agriculture*. 1986;**49**(1):59-74
- [82] Givens DI, Rymer C. Effect of species and genotype on the efficiency of enrichment of poultry meat with n-3 polyunsaturated fatty acid. *Lipids*. 2006;**41**(5):445-451
- [83] Lopez-Ferrer S, Baucells MD, Barroeta AC, Grashorn MA. N-3 enrichment of chicken meat using fish oil: Alternative substitution with rapeseed and linseed oils. *Poultry Science*. 1999;**78**:356-365
- [84] Zelenka J, Schneiderova D, Mrkvicova E, Dolezal P. The effect of dietary linseed oils with different fatty acid pattern on the content of fatty acids in chicken meat. *Veterinary Medicine*. 2008;**53**(2):77-85
- [85] Kartikasari LR, Hughes RJ, Geier MS, Makrides M, Gibson RA. World Congress on Oils and Fats 28th ISF Congress; 2009. pp. 62-63
- [86] Kartikasari LR, Hughes RJ, Geier MS, Makrides M, Gibson RA. Diets high in linoleic acid reduce omega-3 long chain polyunsaturated fatty acids in chicken tissues. In: *Aust. Poult. Sci. Symp. Australia*; 2010. pp. 64-67
- [87] Lopez-Ferrer S, Baucells MD, Barroeta AC, Galobart J, Grashorn MA. n-3 Enrichment of chicken meat. 2. Use of precursors of long-chain polyunsaturated fatty acids: Linseed oil. *Poultry Science*. 2001;**80**(6):753-761
- [88] Svedova M, Vasko L, Trebunova A, Kastel R, Tuckova M, Certik M. Influence of linseed and fish oil on metabolic and immunological indicators of laying hens. *Acta Veterinaria*. 2008; **77**:39-44
- [89] Yang X, Yuming G. Modulation of intestinal mucosal immunity by dietary polyunsaturated fatty acids in chickens. *Food and Agricultural Immunology*. 2006;**17**(2):129-137
- [90] Korver DR, Klasing KC. Dietary fish oil alters specific and inflammatory immune responses in chicks. *Journal of Nutrition*. 1997;**127**(10):2039-2046
- [91] Leshchinsky TV, Klasing KC. Vitamin E and leukocytic cytokine expression in broilers. *Poultry Science*. 2000;**79**(1):37
- [92] Koutsos EA, Klasing KC. Effect of intra-abdominal injection of lipopolysaccharide or muramyl dipeptide on the acute phase response in Japanese quail (*Coturnix coturnix japonica*). *Poultry Science*. 2000; **79**(1):37
- [93] Puthongsiriporn U, Scheideler SE. Effects of dietary ratio of linoleic to linolenic acid on performance, antibody production, and in vitro lymphocyte proliferation in two strains of Leghorn pullet chicks. *Poultry Science*. 2005; **84**(6):846-857
- [94] Adam O. Dietary fatty acids and immune reactions in synovial tissue. *European Journal of Medical Research*, 2003;**8**(8):381-387
- [95] Phipps RP, Stein SH, Roper RL. A new view of prostaglandin regulation of the immune response. *Immunology Today*. 1991;**12**:349-352
- [96] Parmentier HK, Nieuwland MGB, Barwegen MW, Kwakkel RP, Schrama JW. Dietary unsaturated fatty acids affect antibody responses and growth of chickens divergently selected for humoral responses to sheep red blood cells. *Poultry Science*. 1997;**76**(8): 1164-1171
- [97] Sijben JWC, Groot Hd, Nieuwland MGB, Schrama JW, Parmentier HK. Dietary linoleic acid divergently affects immune responsiveness of growing layer hens. *Poultry Science*. 2000;**79**(8): 1106-1115